Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 14 (2016) 768 – 777

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Impact of asphalt ageing on the activity of adhesion promoters and the moisture susceptibility

Tereza Valentová [a], Jan Altman [a], Jan Valentin [a, *]

[a]*Czech Technical University in Prague, Faculty of Civil Engineering, Thakurova 7, Praha 6 – Dejvice, 166 29, Czech republic*

Abstract

Bitumen-aggregate adhesion is one of the crucial characteristics related to an asphalt mix. It affects the mix durability mainly in terms of its moisture susceptibility. Wide range of adhesion promoters is available to the market and can be used in regular practice, nevertheless usually only limited attention is paid to the long term activity (mainly the effective substances) and stability of the additives in the bitumen and the asphalt mix. Research done at the Czech Technical University in Prague is focused on studying the impact of differently aged asphalt mix using selected procedures defined in prEN 12697-52 as well as developing a self-defined procedure by applying the PAV equipment used since many years for long-term bitumen ageing. The results of aged mixtures were always compared to unaged control mixes. In parallel use of aged bitumen was assessed as well. The results were further compared to a simple adhesion test to get a more complex understanding of the activity of selected additives. In total more than 5 additives were selected and tested on one type of asphalt concrete with the application on a more hydrophilic aggregate type. Results gained during this experimental study are presented in the paper using as a criterion indirect tensile strength ratio determined either by EN 12697-12 or by modified procedure according to AASHTO T283.

In parallel because of elevated temperatures used during ageing suitable covering of cylindrical test specimens was analyzed as well to avoid unnecessary deformations or even disintegration of the tested specimens. For this reason two types of protective collar were chosen – PVC and thin steel mash – in both cases fixed by plastic belts. It is assumed that steel mash can better simulate the effect of ageing keeping the envelope partly free for direct contact with hot air and pressure. Results of this comparison are presented in this paper as well.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

* Corresponding author. Tel.: +420-22435-3880.
E-mail address: jan.valentin@fsv.cvut.cz

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.066

Keywords: Bitumen adhesion; adhesion promoter; asphalt ageing; long-term ageing; moisture susceptibility; indirect tensile strength; ITSR

1. Introduction

Prevalent part of the road infrastructure is built with asphalt mixes. However, similarly to any other built structure, also asphalt pavements change their properties and performance with time. Deterioration caused by moisture is seen as one of the key reasons of asphalt pavements deterioration, whereas for their maintenance and rehabilitation are European-wide yearly expended considerable financial means. The moisture can in general act on adhesion loss what is the starting point of many pavement failures. Therefore moisture susceptibility of asphalt mixes is a critical aspect which has to be always evaluated. The typical mechanism of deterioration caused by moisture is reduced adhesion because of water which transfused to the interface of bitumen film and aggregate particle. Then stripping effect of asphalt coating usually starts up to release of particular aggregate particles. The pace of this deterioration is significantly affected also by asphalt mix ageing. It is therefore important to reflect this natural process typical for bitumen if moisture susceptibility is assessed, especially if for reasons of improved adhesion various surfactants are used. To design asphalt mix resistant to water immersion and adhesion problems surfactants are usually added either to the bitumen or to the mix during its production. Their mission is to reduce the hydrophilic behavior of the aggregates. Nevertheless, long term effect of these additives is exactly not known and is subject to many expert discussions. It is further questionable if these additives always deliver the solution for issues induced by moisture in all materials and for all necessary construction processes.

Main objective of the experimental study done by CTU in Prague was the development of suitable procedures for laboratory assessments of asphalt mix durability including the obtaining of knowledge with long term behavior of asphalt mixes in terms of their durability studied by indirect tensile strength test. The effort was to develop a simple and suitable test protocol which would simulate ageing (caused by known factors like oxidation, elevated temperature and UV radiation) and impact of water and frost. At the same time it should simulate conditions of the real paved asphalt layer (compacted specimens with access of air and temperature). To forecast exactly the behavior and properties of aged pavement is as good as impossible because of enormous set of different variables. The study therefore compared suitable experimental methods for asphalt ageing simulation. Use of a suitable test protocol, which would in a best way simulate these conditions, would deliver corresponding experience for determining the asphalt mix durability. During the research stage of this study standardized test methods for either bitumen-aggregate adhesion or moisture susceptibility assessment were used. For ageing it should be stated that this phenomenon is today widely used for bituminous binders. In opposite to that ageing simulation for asphalt mixes is still an area with a lot of discussion and therefore with limited development of commonly acceptable test procedures – even if it is highly important to implement ageing if describing the functional characteristics and performance-based behavior of asphalt mixes.

2. Ageing

Over 30 methods of ageing for either bulk asphalt mix or compacted asphalt test specimens have been developed in the recent decades. For those, the material is usually stored under higher temperature (30 °C to 100 °C) for a stipulated number of hours, days or weeks which is intended to accelerate the oxidative processes caused by atmospheric oxygen. In some cases, pure oxygen or ozone is used as oxidising agent, while elsewhere additional overpressure is applied to speed up the reaction. The ageing methods allow simulating a condition of long-term ageing in several days, thus presenting a situation closely resembling the effect on the layer within the pavement structure after several years. So ageing occurs in two phases, on a short-term scale and, then, subsequently, as long-term ageing. Long-term ageing depends on the short-term ageing; therefore, mix preparation and paving must be performed as well as possible to render the mix less susceptible to ageing over the life-time. In the course of short-term ageing, lightweight compounds evaporate and oxidation occurs during construction. With long-term ageing, steric hardening occurs and the pavement oxidizes over its entire life. The oxidation effect is an irreversible chemical change. Steric hardening, contrastingly, is reversible as it involves a structural re-organization produced by thermal change impact.

In the presented study four types of long-term ageing laboratory procedures were compared, including following conditions:

- Placing bulk asphalt mix at temperature of 85 °C for 9 days in a thermal chamber;
- Conditioning asphalt test specimens at temperature of 85 °C for 5 days;
- Ageing of specimens at elevated temperature of 85 °C and a pressure of 2.1 MPa in PAV for 20 hours;
- Ageing of the bituminous binder applying the short-term ageing TFOT method (3x FTOT).

Within the framework of this study, the simulation of compacted specimen ageing is based on the ageing of the bituminous binder itself in PAV. First, the test specimens are wrapped in a steel mesh that is fastened by assembly ties according to Fig. 1 – wrapped specimen. This keeps the skeleton of the specimen unchanged even under higher pressure and temperature, avoiding deformation which might negatively affect the resulting strength. The prepared specimens are then put on steel plates and gradually placed in the rack according to Figure 1. The rack is then put in the chamber where the specimens are heated up to 85 °C. Once the temperature is reached, the pressure is increased up to 2.1 MPa and maintained for 20 hours.

a)

b)

Fig. 1 (a) test specimens in protective collar in holder for testing in a Pressure Ageing Vessel (PAV); (b) detail of test specimens in protective collar by steel mesh.

3. Input material analysis and mix design

3.1. Input materials

Within this study straight-run bitumen 50/70 fulfilling requirements of CSN EN 12591 was used. For particular tests – mainly the bitumen-aggregate adhesion test according to CSN 73 6161 – several aggregate types have been selected differing in their mineralogy. These aggregates are normally used in the Czech Republic for asphalt mix production. Their specification is summarized in [Valentová 2016]. Based on more detailed analysis one type was later experimentally selected based on characteristics and known mineralogical composition. This selected aggregate type was used for laboratory mix design and moisture susceptibility tests.

To guarantee durability of the mix, some types of aggregate are more or less suitable from the point of view of adhesion between the bituminous binder and the aggregate. To meet the condition of active adhesion, the aggregate must be free of any water to achieve perfect adhesion to the bituminous binder. In contrast to the bitumen, aggregate is often hydrophilic; this means that it absorbs water easily. The following adhesion promoters were used: Impact 8000 with 0.30%-wt. of binder, AdHere LOF 65-00 (0.30%-wt.), Zycotherm (0.10%-wt.), Wetfix BE (0.3%-wt.).

Last but not least mechanical-chemically activated micro-filler originating from the Palestine limestone powders was chosen to act as an intelligent replacement for traditional fillers. It is a dehydrated sludge from limestone marble cutting, further modified by grinding in a special type of high-speed milling machine (disintegrator).

3.2. Input materials

For assessment of ageing impact on durability and adhesion an optimized AC_{bin} 16 mixture was used. Clinkstone aggregates from the quarry Chlum were used known for worse adhesion behavior. The mix design is presented e.g. in [Valentová 2016].

4. Test definition

4.1. Determining adhesion between the binder and aggregate

In the Czech Republic, non-harmonized test according to CSN 73 6161 has traditionally been used to describe the adhesion. It uses a sample of heated aggregate (8/16mm), weight of 300±3 g and binder of 12±0.3 g at a temperature defined depending on the bitumen gradation (160±5 °C for aggregates and 170±5 °C for 50/70 bitumen). After the bitumen coated aggregates are cooled down for 24 hours, the sample is conditioned in water at 60±3 °C for 60 minutes. As soon as the sample has been removed from the water, the coating of aggregate particles is assessed visually and classified according to CSN 73 6161. In this study soliciting comparison with EN 12697-11, test method described in part C was not done.

4.2. Determining the test specimen moisture susceptibility

For the determination of moisture susceptibility usually strength ratios like ITSR (indirect tensile strength ratio), as given in EN 12697-12 are used to assess the effects of water on asphalt mixtures and define its durability. At the same time, the European test was further modified according to the American AASHTO T283 test method which, besides other compaction levels, also introduces specimen saturation with water as well as the application of a single freezing cycle; therefore, two negative effects – water and frost – are combined.

5. Results of the research

5.1. Evaluation of the adhesion test

The adhesion test between bitumen and aggregates involved 8 different types of aggregate and one bitumen representative improved subsequently by chemical adhesion promoters. To verify the effects of adhesion promoters and the effect of storage time, the variants of binders were subjected to short-term ageing *(*TFOT) according to CSN EN 12607-2. The binder was exposed to ageing effects for three times 5 hours at 163 °C. Table 1 summarises the results of unaged binder which indicates the results of one version with reference binder only and the results of a combination with a selected adhesion promoter for each aggregate type. The results were assessed as unsatisfactory for the bitumen without additives and aggregate from Chlum (clinkstone) and Zbraslav (mixed rock: ash rock, metatuf and spilite). The worst results were recorded for aggregate from the Kobylí Hora quarry (granulite), where only 35% of the aggregate remained coated by the bitumen after the adhesion test. The aggregates from Markovice, Libodřice, Měrunice and Zbečno scored as satisfactory; the percentage of aggregate particle coating amounted to roughly 80%. The best result was scored when aggregate from the Litice quarry (spilite) was used; in this case the surface of the aggregate was stripped in approx. 10%, this means good affinity between the binder and the aggregate. The positive effect of the additives could be proven for all types of aggregate. On average, the percentage of coated surface of the aggregate increased by 10% when each individual additive was applied. The additives had the greatest effect on aggregates from Kobylí Hora, Chlum and Zbraslav, which failed the adhesion test without an additive. In these cases the adhesion improved by 20-30%. With the remaining specimens, adhesion improved as well with the only exception of the aggregate from Litice, which scored excellent results even without the additive. A higher dose of additives resulted in a slight improvement of adhesion of the individual aggregate variants; or at least the adhesion did not deteriorate. The only exception was the higher dose of adhesion additive AdHere 65-00 LOF EU, where adhesion deteriorated; however, a repeat measurement was recommended for this case.

Focusing on the comparison of the aged binder, the results are arranged logically (Table 2) as in the preceding case. As is obvious from the measurements, contrary to expectations, ageing has a positive effect on the adhesion of bituminous binders to aggregate. Based on the majority of results, it can be noted that the level of aggregate particle coating by bitumen improves, or the remaining specimens do not demonstrate a deterioration of adhesion. In the case of the reference sample with bitumen 50/70, using the aggregate from Kobylí Hora and Zbraslav, the coating level improved due to the influence of ageing time. In contrast to unaged bitumen, it is visible that the level of coating is going from satisfactory to excellent in the case of aggregate from the Chlum quarry.

Table 1. Results of adhesion test according to CSN 73 6161 for unaged bitumen.

Aggregates	50/70 (reference)		50/70 + 0.3% AdHere 65-00		50/70 + 0.6% AdHere 65-00		50/70 + 0.3% Impact 8000		50/70 + 0.6% Impact 8000		50/70 + 0.1% Zycotherm		50/70 + 0.3% Wetfix BE	
Markovice	B-C	85%	B	90%	B-	87%	A-B	95%	B-	87%	B +	93%	B-	87%
Litice	B	90%	B-C	85%	C-D	75%	B-	87%	B-	87%	B -C	85%	B-C	85%
Libodrice	C	80%	A -	97%	C+	83%	A-	97%	C+	83%	A-B	95%	B	90%
Chlum	D +	73%	C	80%	A-B	95%	C-	77%	C	80%	C -	77%	C	80%
Kobyli Hora	E	50%	C	80%	C-D	75%	C	80%	B-C	85%	C	80%	C	80%
Měrunice	C -	77%	B -	87%	A-B	95%	A-B	95%	B	90%	B +	93%	B-C	85%
Zbraslav	D	70%	B -	87%	C+	83%	B-C	85%	B-C	85%	C +	83%	B-C	85%
Zběcno	C	80%	C +	83%	B-C	85%	B-C	85%	B-C	85%	B -C	85%	B-C	85%

Table 2. Results of adhesion test according to CSN 73 6161 for aged bitumen.

Aggregates	50/70 (reference)		50/70 + 0.3% AdHere 65-00		50/70 + 0.6% AdHere 65-00		50/70 + 0.3% Impact 8000		50/70 + 0.6% Impact 8000		50/70 + 0.1% Zycotherm		50/70 + 0.3% Wetfix BE	
Markovice	B	90%	A-B	95%	B+	93%	A-B	95%	B+	93%	B	90%	A-	97%
Litice	C-	77%	C	80%	C	80%	B	90%	A-	97%	B	90%	B	90%
Libodrice	B-C	85%	B-	87%	B-	87%	B	90%	A-B	95%	C+	83%	B-C	85%
Chlum	A-	97%	A-B	95%	B	90%	C	80%	B-C	85%	C	80%	B+	93%
Kobyli Hora	C-	77%	C+	83%	C	80%	C-D	75%	C+	83%	B-C	85%	A-B	95%
Měrunice	B	90%	B-	87%	B-C	85%	B	90%	B	90%	B	90%	B+	93%
Zbraslav	B-C	85%	B-C	85%	C+	83%	C+	83%	B	90%	B-C	85%	B-C	85%
Zběcno	C	80%	B	90%	B-C	85%	B-	87%	B-	87%	B	90%	B-	87%

6. Evaluation of moisture susceptibility test

The study involved the preparation of one set of test specimens with the reference binder as well as 6 variants of asphalt mixes with additives to improve adhesion. Selected laboratory ageing methods were evaluated in all variants of mix AC_{bin} 16; a set of unaged specimens was prepared for the sake of the overall assessment. A simple comparison of indirect tensile strengths compared the effect of individual variants of adhesion improvement both prior to ageing and after the selected simulations of ageing of test specimens or bulk asphalt mix.

6.1. Comparison of indirect tensile strength

The following Fig. 2 compares the indirect tensile strenghts (ITS) of test specimens left in air, both for the unaged asphalt mix versions and for selected laboratory aged variants. Focusing on the first columns of individual

variants of the mixes unaffected by ageing, the following findings can be highlighted. The reference mix reached the indirect tensile strength of 2.39 MPa. The mix variant using a mechanical-chemically activated micro-filler scored almost the same result as the reference mix. The diagram also shows that the application of adhesion promoters decreased the indirect tensile strength in comparison to the reference mix. The greatest reduction by 0.48 MPa in comparison to the reference mix was observed for the variant with Zycotherm and in the case of a higher dose of Impact 8000. However, the difference could have been caused by insufficient tempering of the test specimens. As suggested by the latest results of a partial research just completed, testing indirect tensile strength at different temperatures showed an increase of the strength on average by 17.5% if the test temperature was by 2 °C above the prescribed temperature of 15 °C; on the other hand temperature by 2 °C below the prescribed value reduced the strengths by 3,8%. It is obvious that even the slightest change in testing temperature affects the results as such.
The second columns (black shading) represent the ITS of test specimens where the first method of laboratory ageing was applied. The method consisted of preparing Marshall test specimens which are then put in a climatic chamber with forced circulation at 85 °C for 5 days. As is obvious from the results, strength of the reference mix and of mix with a higher dose of AdHere additive showed lower strength than unaged mix; for the remaining mixes, the indirect tensile strengths increased which was one of the assumptions. Comparing the results of aged test specimens, the mix with Zycotherm and micro-filler demonstrate higher strengths than the reference mix (by 0.28 MPa and 0.40 MPa, respectively). The remaining values are similar, or lower on average.

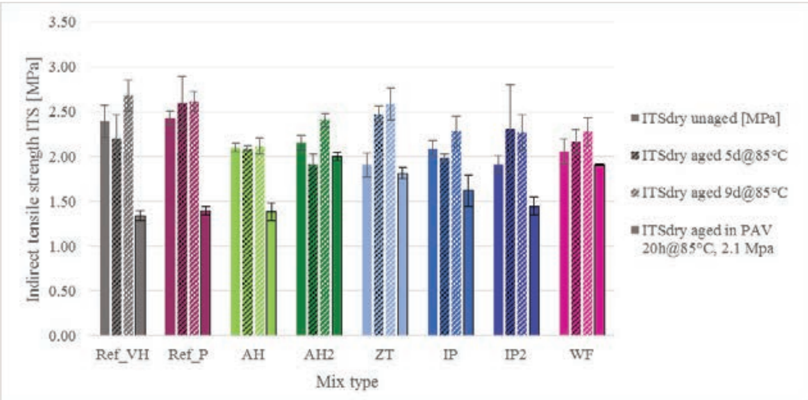

Fig. 2. Comparison of indirect tensile strengths of test specimens left in air.

The third columns (white shading) indicate the results of the second method of laboratory ageing where the asphalt mix was distributed evenly on a pre-prepared mat where the mix was aged in the climatic chamber with forced circulation at 85 °C for 9 days. When the time was up, test specimens were compacted fo each mix by Marshall compactor (2x25 blows) and subsequently used to determine moisture susceptibility. The third series of results shows that the reference mix had the highest indirect tensile strength of 2.68 MPa, the mix with micro-filler and Zycotherm scored almost identical result. For the other mixes, the results of indirect tensile strength were lower when compared to the reference mix. When the variants were compared to one another, it is obvious that the ageing of bulk asphalt mixes affects the subsequent test specimen compaction and strengths in comparison to unaged test specimens where they score 10% more (or, in the case of Zycotherm, about 35%). The ageing of test specimens as such does not demonstrate the same tendeny in all cases which might be caused by the laboratory ageing method applied where the specimens are placed in a climatic chamber at higher temperature; this might cause deformation and the specimens may lose the original volume.

Last column shows indirect tensile strength values for test specimens which were laboratory aged by the PAV method at elevated temperature and pressure. In comparison to the previous test methods of simulated ageing it is obvious that considerable drop in ITS values was reached mainly for control mix and mix with filler substitution. In the case of mix option with higher content of adhesion promoter AdHere and Wetfix the results after PAV ageing are close to the ITS values gained also during the remaining laboratory ageing test procedures. In these cases only minimum drop in ITS values was gained.

6.2. Evaluation of moisture susceptibility of test specimens, including one freezing cycle

The effect of adhesion promoters on asphalt mix resistance to negative effect of water was compared for all seven mix options. The results of the testing according to EN 12697-12 are represented graphically in Fig. 3-5. The results were viewed from several perspectives. The first question concerned the effect of the adhesion promoter applied from the point of view of moisture susceptibility, i.e. whether the ITS ratio improves or not. It was also assessed whether the indirect tensile strength ratios meet the minimum required value as stipulated by the national annex to standard CSN EN 13108-1 for asphalt mixes AC_{bin} (at least 80%). If evaluating test specimens exposed to adverse effects of water with one freeze cycle neither US standard AASHTO T 283-03 nor the national annex to standard CSN EN 13108-1 stipulates a minimum ITSR threshold. For the purposes of experimental comparisons, such threshold was set to 70% within this study. When indirect tensile strengths of unaged specimens (see Fig. 2) were compared, it could be noted that the specimens exposed to adverse effects of water reached the threshold of ITSR = 0,80 in almost all variants. Focusing on comparison of individual variants, the mixes with higher content of AdHere 65-00 LOF EU recorded a reduction in ITSR to 0,65. Contrary to the expectations, the results demonstrated that, the application of adhesion promoter had no effect on improving moisture susceptibility in comparison to the reference mix. The conclusions are confirmed by the values measured in test specimens exposed to adverse effects of water, including the freezing. In that case, the ITSR was set to 0,79 for the reference mix; the same was achieved by the variants with micro-filler and Zycotherm or Wetfix BE. For the remaining variants, the indirect tensile strength ratio decreased almost to 70% which was determined as the threshold.

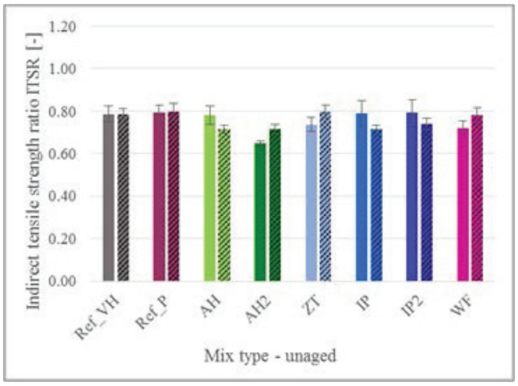

Fig. 3. Results of ITSR test; unaged asphalt mixes.

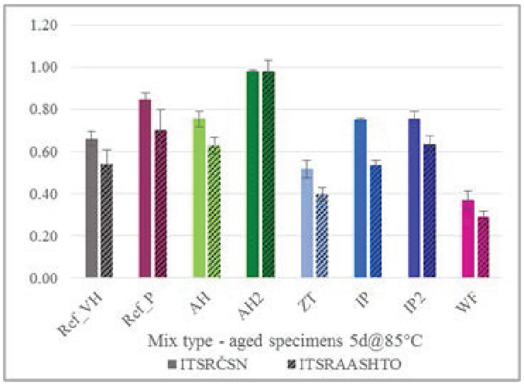

Fig. 4. Results of ITAR test; aged asphalt test specimens 5d@85 °C.

Fig. 4 gives an overview of the ITSR results for test specimens exposed to ageing for 5 days at 85 °C. Focusing on the ITSR according to CSN EN standard, it can be noted that the best results were achieved by the variant with a higher content of AdHere 65-00 LOF EU. The ITSR amounts to nearly 0.98 while a similarly high value was achieved by the AASHTO method although the procedure is based on less favourable conditions affecting the asphalt mix under observation. The mix option with micro-filler reached a 0.85 limit which meets the minimum threshold required. Out of the remaining mixes, the variant with a lower proportion of AdHere and the variant with Impact come close to the threshold. It is obvious that a higher dose of the additive with the aggregate concerned has no potential to improve moisture susceptibility as is also confirmed by the results according to AASHTO method. The poorest results in ITSR were recorded by the asphalt mix with Wetfix where the ratio came to 0.37 for the European approach and 0.29 for the American test method, i.e. almost fifty per cent less than the value of the reference mix. The aforementioned result is at least noteworthy; it might point out some restrictions of the test method. When compared to Wetfix, the variant with Zycotherm scored better (0.52 vs. 0.40); however, the mixes do not meet the required minimum ITSR thresholds anyway.

Focusing on the results of test specimens made of aged bulk asphalt mix, the results in Fig. 5 are of interest. The moisture susceptibility results determined according to CSN EN methods and the US test method yield almost identical ITSR values, despite the fact that the latter method exposes the test specimens to less favourable conditions. When compared to the reference mix where the ITSR amounts to 0.71 and 0.68, we can note that neither Impact 8000 in a content of 0.3% and 0.6%, nor Wetfix delivered any improvement in adhesion; the ITSR ratio amounts to 0.60 on average. An improvement was recorded in the case of micro-filler application and for AdHere content of 0.3%. In these cases, the ITSR amounts to roughly 0.90. Higher content of AdHere resulted in further improvements.

6.3. Results of PAV asphalt mix ageing

Ageing of test specimens at elevated temperature and pressure in PAV apparatus had essential impact on indirect tensile strength values. In opposite to remaining used methods of simulated ageing the test specimens in this case were subjected to less favorable conditions. Overall they might maybe better simulate the impacts of adverse conditions during the entire life-time of an asphalt mix in a pavement. If focusing on comparison of test specimens with respect to moisture susceptibility according CSN (see Fig. 6), it is obvious that selected options reach more or less in all cases the required limit of ITSR = 80%. The only exception is asphalt mix containing Zycotherm additive, where the ITSR value was 0.74. Second column demonstrates results of indirect tensile strength ratios according to modified AASHTO test procedure. The lowest values were gained again in the case of asphalt mix with Zycotherm, but surprisingly also for higher addition of Impact promoter, where the ITSR reached only 0.66. All remaining mix options reached a minimum value of 70%, whereas the best results were shown for the option containing pulverized filler from Palestinian limestone (0.90) as well as for mixes with AdHere (0.83) or Wetfix (0.81) adhesion promoters.

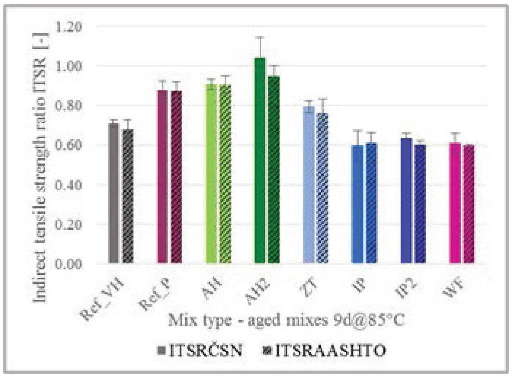

Fig. 5. Results of ITSR test; aged bulk asphalt mix 9d@85 °C.

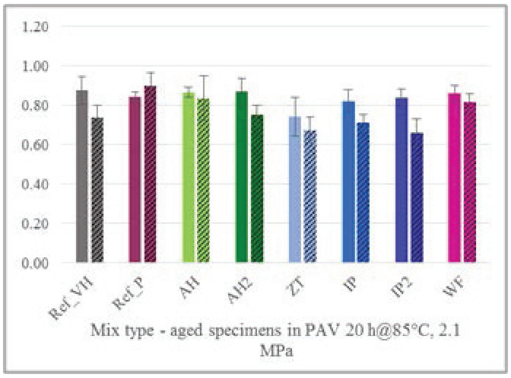

Fig. 6. Results of ITSR test; PAV 20h@85 °C, 2.1 MPa.

6.4. Comparison of different test specimen covering for ageing in the tempering chamber under higher temperature

As has been mentioned in Chapter 2.2, this study has also examined the effect of a higher temperature, i. e. 85 °C, when the test specimens were placed in the tempering chamber for 5 days during the ageing process. To evaluate the effect of the thermal conditioning on specimen dimensions three sets of specimens were prepared within the framework of the test; the first set was placed freely in the tempering chamber. For the second set, a protective collar was made with a PVC cover and ties to avoid deformation due to temperature. In the case of the last set of specimens, the PVC cover was replaced by a steel mesh which was supposed to simulate the real-life conditions better with respect to air access in the tempering chamber not only from the top and bottom of the specimen but also from the sides to ensure its even ageing. Both types of test specimen cover are documented in Fig. 7.

a) b)

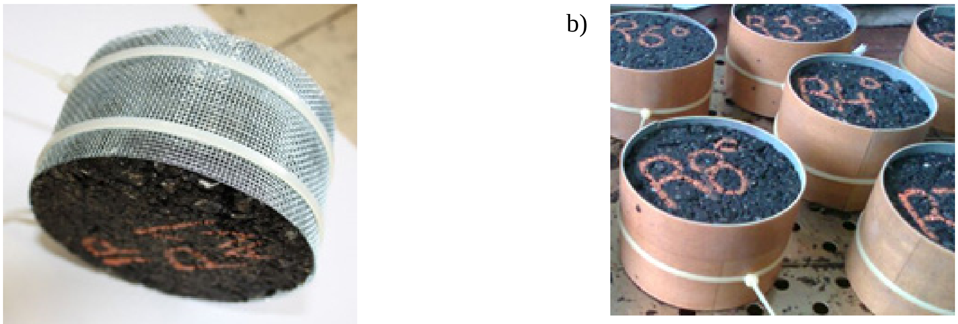

Fig. 7 (a) The test specimen with a protective collar created by a steel mesh and tightening straps; (b) test specimens with a PVC case.

The effect on asphalt mix bulk density was observed for the test specimens. For the sake of simple comparison indirect tensile strength was determined for all the specimens. The results are summarized in Table 3.

Table 3. Results for test specimen in different a protective collar – aged specimen 5d@85 °C.

Mix type	Mix acronym	ITS_{dry}	Standard deviation	$ITSR_{C\ SN\ EN}$	Standard deviation	IT SR_{AASHTO}	Standard deviation
ACL 16+ Chlum Velke Hydcice	R_VH'	2.40	0.33	0.65	0.04	0.48	0.06
ACL 16+ Chlum_Velke Hydcice_PVC	R_VH°	2.29	0.07	0.81	0.03	0.72	0.04
ACL 16+ Chlum Velke Hydcice a sturdy metal mesh	R_VHSD	2.21	0.18	0.86	0.05	0.85	0.08
ACL 16+ Chlum micro-filler Palestina	R_K'	2.60	0.29	0.85	0.03	0.70	0.10
ACL 16+ Chlum micro-filler PVC	R_K°	2.67	0.26	0.81	0.02	0.67	0.05
ACL 16+ Chlum micro-filler a sturdy metal mesh	R_KS°	2.04	0.05	0.94	0.03	0.85	0.03

For both selected mixes, the impact on moisture susceptibility as depicted in Tab. 3 was monitored, too. The best results of indirect tensile strength ratios were achieved when steel mesh was applied. In this case, the test specimens are allowed to age evenly, air circulation facilitates even ageing just like in the case of freely placed specimens; however, when the mesh is used, there are no further deformations or disintegration. Covering the specimens with PVC prevents air access in the tempering chamber with forced air circulation and the specimens thus cannot age evenly. The results allow assumptions on the positive effect of a protective steel mesh collar; however, the ageing of test specimens in PAV plays a significant role in the method since it takes into account, besides the higher temperature, also the pressure which has a much less positive impact on the test specimens (they are much more susceptible to deformation, or complete disintegration).

Conclusions

The issue of adhesion between aggregate and bituminous binders as well as the closely related aspect of durability tested by asphalt mix resistance to water remains one of the longest studied asphalt mix phenomena. Similarly to the ageing of bitumen and asphalt mixes, we still cannot describe and verify all phenomena affecting the adhesion as such with clarity and certainty since there are both physically-mechanical and chemical aspects of the issue as such. Moreover, if the two phenomena are combined they allow us to reflect the real-life conditions much better; however, the problem becomes more complex at the same time.

The presented study delivered results which make it obvious that the used adhesion test provides quick information on the quality of aggregate particle coating by bitumen; the disadvantage is its considerable dependence on the evaluator's subjective impression and the fact that the method applied is quite difficult to relate to any real-life effects in the pavement structure. The subjective evaluation aspect can surely be eliminated by more exact and more demanding methods (e.g. determining the contact angle), the problem of making the test conditions more realistic should be taken into account at least by considering the ageing aspect, but also by the possible effects of not only the water-elevated temperature combination but a more complex water-frost-temperature-time approach. Due to that, we tried to take into account at least the time (and ageing) factor in the partial assessment. This can help to at least indicate the stability of surfactant effects.

The issue of asphalt mix ageing and water susceptibility is similarly complex. Firstly, we have to say that regardless of the interpretation of what period is simulated by the specific ageing method, it is appropriate to assess aged asphalt mixes. The effect undoubtedly occurs in the pavement structure and it is unimportant, from the perspective of life and effect of the adhesion promoters, what occurs e.g. during the first year; the important thing is how effective it will be on the overall asphalt mix behaviour after 5 or more years. The ageing of compacted test specimens is probably better in simulating the actual situation in the pavement although, on the other hand, the level of compaction of the asphalt mix within the pavement is higher than the selected approach with 2x25 impacts which is considered for the purposes of simulating accelerated water effect. In the case of bulk asphalt mixes, the results seemed more consistent; this approach to ageing is simpler to perform and the test specimens are not deformed at all. On the other hand, the bitumen film ages evenly throughout the mix; this does not reflect the likely situation of a compacted asphalt layer. Therefore, what is simulated by this approach is a matter of interpretation. Last but not least, particularly in areas where cold and hot climates alternate, a change of the existing methodology of moisture susceptibility evaluation must be supported and a freezing cycle added to the test as this has an impact on the pavement structure and affects the durability of the asphalt mix.

Acknowledgement

This paper was prepared under the funding scheme of a student grant project at CTU Prague, project No. SGS15/049/OHK1/1T/11.

References

AASHTO Designation: T 283-03 (2007). Standard Method of Test for: Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage. Washington: American Association of State and Highway Transportation Officials.

Altman, J., (2014). Conditions for water susceptibility testing on asphalt mixes. Bachelor thesis. Faculty of Civil Engineering CTU Prague, (in Czech).

Bell, C.A., Sosnovske, D. (1994). Aging: Binder validation. National Research Council, Strategic Highway Research Council. Washington, D.C. ISBN 03-090-5802-3.

ČSN 73 6161 (2000). Determination of adhesion between bitumen and aggregates. Czech Standardization Institute, Prague,.

ČSN EN 12697-12 (2005). Bituminous mixtures - Test methods for hot mix asphalt - Part 12: Determination of the water sensitivity of bituminous specimens. Czech Standardization Institute, Prague.

ČSN EN 12697-23 (2005). Bituminous mixtures - Test methods for hot mix asphalt - Part 23: Determination of the indirect tensile strength of bituminous specimens. Czech Standardization Institute, Prague.

Grenfell, J.et al. (2013). Assessing asphalt mixture moisture susceptibility through intrinsic adhesion, bitumen stripping and mechanical damage. Road Materials and Pavement Design. 2013, 15(1): 131-152. DOI: 10.1080/14680629.2013.863162. ISSN 1468-0629. Available from: http://www.tandfonline.com/doi/abs/10.1080/14680629.2013.863162

Hofko, B., Hospodka, M., Eberhardsteiner, L., Blab, R. (2015). Recent Developments in the Field of Ageing of Bitumen and Asphalt Mixes. Proceedings of Pozemní komunikace 2015 conference. Czech Technical University in Prague.

Islam, M.R., Hossain, M.I., Tarefder, R.A. (2015). A study of asphalt aging using Indirect Tensile Strength test. Construction and Building Materials. DOI: 10.1016/j.conbuildmat.2015.07.159. ISSN 09500618. Accessible from: http://linkinghub.elsevier.com/retrieve/pii/S0950061815301720)

Valentová, T. (2012). Effect of microfiller and selected adhesion promoters on adhesion of asphalt mixture. Bachelor thesis. Faculty of Civil Engineering CTU Prague (in Czech).

Valentová, T. et al. (2016). Development and verification of a suitable methodology for stability assessment of bitumen adhesion promoters. Proceedings of 6th Eurobitume & Eurasphalt Congress, Prague (in review).